FESC
Florida Energy Systems Consortium

FLORIDA STATE UNIVERSITY
Real-Time Power Quality Study For Sustainable Energy Systems

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Description: The main objective of this project is the collection of preliminary data for IESES proposals that can be used to seek local, national and international sources of external funding from private and government sponsors. The overall project has been split up in several independent subprojects to allow a timely completion of the tasks. Four tasks have been completed and one task is still ongoing. The remaining task will be performed by the CO-PIs and their graduate students at Florida State University.

Budget: $15,000
Universities: Florida State University

Progress Summary

Task 1: "Sustainable Energy White Paper Development" has been completed. Two proposals have been submitted and one conference paper has been published: Indranil Bhattacharya and Simon Foo, "Indium Phosphide, Indium-Gallium-Arsenide and Indium-Gallium-Antimonide based High Efficiency Multijunction Photovoltaics for Solar Energy Harvesting," 1st Asia Symposium on Quality Electronic Design (ASQED '09), Kuala Lumpur, Malaysia, July 15-16, 2009.

Fig. 1 Instrumental PEM fuel cell station. 1.2 KW

Task 2: "IESES Collaboration within State of Florida" to develop dynamic models for fuel cell, battery and ultra-capacitors has nor been completed. We will travel to seek collaborations with the University of Miami and write proposals in the near future. Project funds will be used for travel expenses seeking collaboration opportunities within the State of Florida. This task is still ongoing.

Task 3: "IESES International Collaborations" has been completed. To meet Florida's sustainable energy demands, we have addressed the important problems on power quality. The preliminary study showed that a custom microprocessor should be favored. Currently the leader in ESL design of microprocessors is the Processor Designer (PD) by Coware Inc. These tools have been originally developed at RWTH Aachen in Germany and are now commercial products. To learn the use of these tools, the PI visited the RWTH Aachen in the summer of 2009 for 2 month (June and July) and was trained on using the various design tools. In the following, we have successfully installed the Pocessor Designer tools at FSU College of Engineering computers and became member of the CoWare University program. The tools (16 seats having a total commercial value of 16x$120K=$1.920 MUSD) are in use in the Fall 2009 ASIC System design course (EEL5707). 3 students in this course were MS students from CAPS. Data produced during the research stay at RWTH Aachen resulted in the submission of 2 journal publications and will be used later to submit proposal in related calls.

Task 4: "Power Quality Preliminary Data Production" is complete. We have compared the preliminary study from the FSU Ph.D. thesis "FPGA-Based Real-time Processing of Time-varying waveform Distortions and Power Disturbances in Power Systems" by Jinglin Xu with current state-of-the art systems. It turns out that commercial switching to an alternative source after detecting a power distortion is done within 2ms. As a result the narrow band filter approach used in harmonic analysis cannot be used.

The study of low latency, robust, and efficient systems uncover that a zero or first order Hilbert Transformer. We have successfully designed, built in MatLab/Simulink, simulated and tested on an FPGA board such a system using first and second order Hilbert transformers and could successfully implement a sag/swell detection under the 2 ms requirements. We have included this MatLab/Simulink experiments in the "DSP with FPGAs" CCLI phase II proposal to NSF in the spring 2010.

Task 5: "Power quality analysis of PEM fuel cell system" has been completed. We have made available to the team PEM fuel cell systems to evaluated prototypes of power quality control systems. In particular we collaborated with Dr. Li's group in the testing of hybrid energy storage systems for fuel cell applications. Our group provided a 1.2kW fuel cell which was integrated with the hybrid energy storage and power conversion systems. Our teams tested different load profiles representative of transportation applications. The imposed load profile resulted in the FC power output and fuel consumption was measured. The power management strategy target was to keep the FC output nearly constant and have the storage elements respond to load variations. Different control strategies were tested trying to identify the one that leads to minimum fuel consumption for a given mission (load characteristics).

2010 Annual Report

Objectives

The objective of this report is to show the progress we made towards the collection of preliminary data for IESES proposals that can be used to seek local, national and international sources of external funding from private and government sponsors.

Status of Work

The overall project has been split up in several independent subprojects to allow a timely completion of the tasks. Three tasks have been completed and 2 tasks are still ongoing.

The remaining tasks will be performed by the CO-PIs and their graduate students at Florida State University.

Task 1: Sustainable Energy White Paper Development (Dr. Foo) Status: Completed

Brief Summary of Accomplishment:

The $3000 funding was used wholly to support one (1) graduate student to develop research white papers in the area of sustainable/renewable energy. The main result of this effort is the development of a research proposal titled "Technical and Economic Impacts of High Efficiency Multijunction Solar Cells in High Penetration Solar Deployment," to be submitted to the Department of Energy (DOE). Other accomplishments during this period include

- One (1) conference paper has been published (see Appendix).

  Bhattacharya and S. Y. Foo, "Indium Phosphide, Indium-Gallium-Arsenide and Indium-Gallium-Antimonide based High Efficiency Multijunction Photovoltaics for Solar Energy Harvesting," 1st Asia Symposium on Quality Electronic Design (ASQED '09), Kuala Lumpur, Malaysia, July 15-16, 2009.
- One internal proposal titled "Developing Super-High-Efficiency Multijunction Photovoltaics for Solar Energy Harvesting," has been submitted to the FSU CRC Planning Grant, Fall 2009.

Task 2: IESES Collaboration within State of Florida (Dr. Li) Status: Ongoing

To meet Florida's sustainable energy demands:

1. We will develop dynamic models for fuel cell, battery and ultra-capacitors.
2. We will travel to seek collaborations with the University of Miami and write proposals in the near future.

The $3,000 will be used for travel expenses seeking collaboration opportunities within the State of Florida.

Deliverables:
Technical report on dynamic models to be used for white paper or proposals.
Report on collaboration opportunities.

Task 3: IESES International Collaborations (Uwe Meyer-Baese) Status: Completed.

To meet Florida's sustainable energy demands, we have addressed the important problems on power quality. The preliminary study used was based on the FSU Ph.D. thesis "FPGA-Based Real-time Processing of Time-varying waveform Distortions and Power Disturbances in Power Systems" by Jinglin Xu. In this study MatLab/Simulink based power quality algorithms had been implemented on a real-time FPGA system. It turn out that the narrow band signal processing in the harmonic analysis requires very long word length in the digital signal processing to avoid overflows. As a suggested solution a floating point (FP) processing approach was considered. However, FP operations such as add or multiplier require large resources on an FPGA, and therefore a sequential FSM/microprocessor approach was favored. In a microprocessor solution the high processing power of a datapath design is traded to a more efficient area design. The second argument for a microprocessor system was that the system should be able to submit related data over the internet. Implementing a web server in HDL seemed too complex and software in the programming language C seemed more appropriate.

Currently the leader in ESL design of microprocessors is the Processor Designer (PD) by Coware Inc. These tools have been originally developed at RWTH Aachen in Germany and are now commercial products. To learn the use of these tools, the PI visited the RWTH Aachen in the summer of 2009 for 2 month (June and July) and was trained on using the various design tools and IPs like IEEE FP multiplier, adder, comparison and C compiler development using the CoSy semiautomatic development flow.

In the following, we have successfully installed the embedded microprocessor tools developed at RWTH Aachen and now a commercial product of CoWare Inc. at FSU College of Engineering computers. We have become member of the CoWare University program that allows us now to train our students and do research in the embedded microprocessor field. The tools (16 seats having a total commercial value of 16x$120K=$1.920 MUSD) are in use in the Fall 2009 ASIC System design course (EEL5707). 3 students in these courses are MS students from CAPS. Data produced during the research stay at RWTH Aachen resulted in the submission of 2 journal publications and will be used later to submit proposal in related calls.

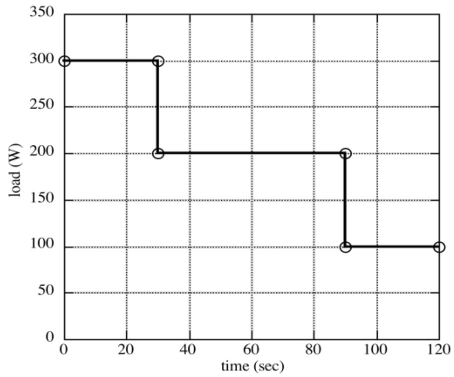
Task 4 Power Quality Preliminary Data Production (Anke Meyer-Baese) Status: Completed.

We have compared the preliminary study from the FSU Ph.D. thesis "FPGA-Based Real-time Processing of Time-varying waveform Distortions and Power Disturbances in Power Systems" by Jinglin Xu with current state-of-the art systems (e.g. J. Arai, K. Iba, T.Funabashi, Y. Nakanishi, K. Koyanagi, R. Yokoyama (2008) "Power Electronics and Its Application to Renewable Energy in Japan" IEEE Circuits and Systems, 3/Q, p. 52-66). It turns out that commercial switching to an alternative source after detecting a power distortion is done within 2ms. As a result the narrow band filter approach used in harmonic analysis cannot be used. The study of low latency, robust, and efficient systems uncover that a zero or first order Hilbert

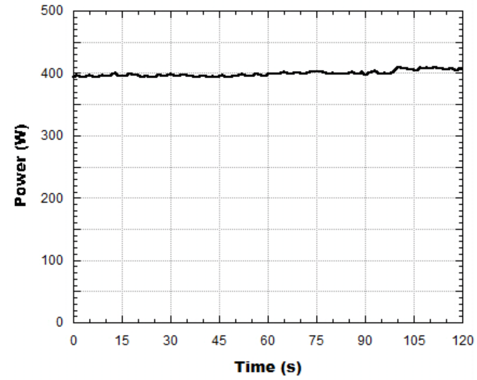
Transformer, popular in narrow band communication systems seemed to be a better choice (see Meyer-Baese. "Universal Hilbert Sampling Receiver with CORDIC-Demodulation (in German)," Funkuhren Zeitsignale Normalfrequenzen, May 1993, pp. 65-81). The Hilbert transformer produces a 90 degree phase shift and then a CORDIC processor is used to compute the amplitude. The Hilbert transformer should be a-symmetric to achieve a short latency
We have successfully designed, built in MatLab/Simulink, simulated and tested on an FPGA board such a system using first and second order Hilbert transformers and could successfully implement a sag/swell detection under the 2 ms requirements.
We intend to include this MatLab/Simulink experiments in the "DSP with FPGAs" CCLI phase II proposal to NSF in the spring.
We have revised our paper "FPGA-based Solution for Real Time Tracking of Time-varying Harmonics and Power Disturbances" and resubmitted to Int. J. of Power Electronics. The reference number is IJPELEC-13422.

Task 5: Real-time power quality study for sustainable energy systems (Juan Ordonez) Status: completed
We have made available to the team PEM fuel cell systems to evaluated prototypes of power quality control systems. In particular we collaborated with Dr. Li's group in the testing of hybrid energy storage systems for fuel cell applications. Our group provided a 1.2kW fuel cell which was integrated with the hybrid energy storage and power conversion systems. Our teams tested different load profiles representative of transportation applications.

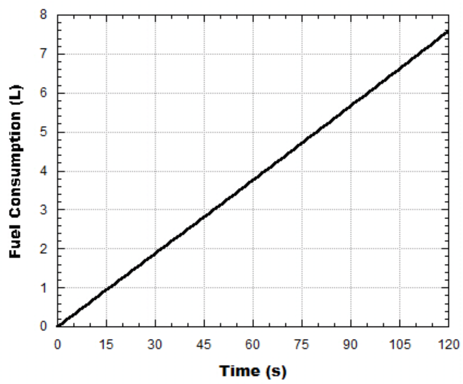
• Instrumented PEM fuel cell station. 1.2 kW stack and single cells



Load profile: 100% of full load, 65% of full load and 33% of full load



Fuel cell power profile during the cycle for constant power (120s)



•Fuel consumption during the cycle for constant power.

An example of the tests conducted is illustrated in the figures above. The imposed load profile resulted in the FC power output and fuel consumption illustrated. The power management strategy target was to keep the FC output nearly constant and have the storage elements respond to load variations. Different control strategies were tested trying to identify the one that leads to minimum fuel consumption for a given mission (load characteristics).

Schedule and Cost Proposal

The 2 additional proposed tasks will be performed within the next few months. At the end of the project a comprehensive final report with all major findings, activities and results will be delivered.